AEOLIAN PROCESSES AT THE MARS EXPLORATION ROVER *OPPORTUNITY* LANDING SITE.
R. Sullivan[1], J. F. Bell III[1], W. Calvin[2], D. Fike[3], M. Golombek[4], R. Greeley[5], J. Grotzinger[3], K. Herkenhoff[6], D. Jerolmack[3], M. Malin[7], D. Ming[8], L. A. Soderblom[6], S. W. Squyres[1], S. Thompson[5], W. A. Watters[3], C. Weitz[9], A. Yen[4], [1]Cornell University, Ithaca NY 14853, [2]University of Nevada, Reno, Reno, NV, [3]Massachusetts Institute of Technology, Cambridge, MA, [4]Jet Propulsion Laboratory, Pasadena, CA, [5]Arizona State University, Tempe, AZ, [6]U. S. Geological Survey, Flagstaff, AZ, [7]Malin Space Science Systems, San Diego, CA, USA, [8]NASA Johnson Space Center, Houston, TX, [9]Planetary Science Institute, Tucson, AZ.

Introduction: The traverse of the Mars Exploration Rover *Opportunity* across its Meridiani Planum landing site has shown that wind has affected regolith by creating drifts, dunes, and ubiquitous ripples, by sorting grains during aeolian transport, by forming bright wind streaks downwind from craters seen from orbit, and by eroding rock with abrading, wind-blown material.

Wind Streaks: Pre-landing orbiter observations showed bright and dark streaks tapering away from craters on the Meridiani plains.[1] Further analysis of orbiter images shows that major dust storms can cause bright streak orientations in the area to alternate between NW and SE, implying bright wind streak materials encountered by *Opportunity* are transient, potentially mobilized deposits. *Opportunity* performed the first in situ investigation of a martian wind streak, focusing on a bright patch of material just outside the rim of Eagle crater. Data from Pancam, the Miniature Thermal Emission Spectrometer (Mini-TES), the Alpha-Particle X-Ray Spectrometer (APXS), and the Mössbauer spectrometer either are consistent with or permit an air fall dust interpretation[2,3]. We conclude that air fall dust, deposited in the partial wind shadow of Eagle crater, is responsible for the bright streak seen from orbit, consistent with models involving patchy, discontinuous deposits of air fall dust distributed behind obstacles during periods of atmospheric thermal stability, e.g., during major dust storms[4,5].

Bedforms: Aeolian ripples with cross-sections commonly ~1 cm high and 10 cm wide, and crest-line lengths ranging up to 2 m, dominate the dark plains. Larger examples occur on rims adjacent to shallow depressions. Well-sorted, ~1 mm fragments of hematite-enriched spherules completely cover ripple surfaces, but the flat intervening areas between ripples are dominated by much smaller 50-125 μm basaltic grains that partly bury additional spherule fragments. Intact spherules are found scattered only between ripples, generally perched on the basaltic sand there**.** Mössbauer contact plate impressions into these areas reveal weak cohesion between sand grains, contrasting with obvious indications of loose sand seen within depressions functioning as aeolian traps. On the plains, much of the 50-125 μm sand evidently has remained inactive long enough for slight cohesion to form between grains by some unknown process. This implies similar inactivity of the much larger (harder-to-move) spherule fragments on the plains as well. We conclude the plains ripples have not been active as recently as other bedforms described below. Individual plains ripples are oriented about ~N26E but commonly are grouped en echelon defining an older orientation of about N4E, indicating a clockwise change in wind direction.

Ripples in depressions serving as particle traps generally are different from plains ripples, being composed of basalt sand only and having profiles dominated by continuously concave (not flat) troughs connected by narrow crests. The Eagle floor ripples are aligned with the crater's S45E bright wind streak, were trenched more easily by the rover wheel than any other material, and appear especially clean in MI images. These bedforms probably are currently mobilized by the same winds forming the bright wind streak.

Opportunity observed a complex of larger bedforms spanning about 50 m on the floor of Endurance crater that morphologically resemble terrestrial star dunes. Other dark sands within Endurance occur in small drifts associated with rocks, and in rippled deposits contrasting with surface textures of larger bedforms they lie against. A Mössbauer impression into one small drift near a rock revealed cohesionless, therefore probably active, basaltic sand.

Rock Abrasion: Ventifacts have been recognized on outcrop material where *Opportunity* has approached closely. Small rock protrusions extend from some spherules partially embedded in outcrop, representing erosional remnants in wind shadows behind the more resistant spherules. Because these features occur in rock, they may represent long timescale records of the strongest unidirectional winds, and possibly the directions to major sediment sources. Rock tails do not occur in every rock unit exposed at Eagle and Endurance craters. Orientations of spherule tails show two modes: 284±28° (n=107), and 135±25° (n=25). The first azimuth is aligned approximately with winds driving plains ripples (including the N26E and older N4E orientations). The second azimuth is consistent with one of the current wind directions associated with bright streaks. Spherule rock tails show how aeolian abrasion can erode exposed rock and release spherules from outcrop across the landing site. Ejecta blocks mostly perched on the surface are scattered around the rim of Fram crater, but are absent around the rims of the larger, but older, Eagle and Endurance craters; aeolian erosion likely is responsible for eroding away ejecta blocks originally perched on these crater rims.

Saltation/Suspension Transition: The gradual transition from aeolian saltation to suspension commonly is defined as where threshold-of-motion wind friction speed, u_{*t}, for a particle begins to exceed its terminal fall velocity, u_F. For terrestrial conditions, this particle size is around 50 μm, but is expected to be around 200 μm for Mars due to higher u_{*t} values for all particle sizes and lower gravity[6-9]. On Earth dune sand is several times the transitional particle size, so this is anticipated also to be the case on Mars.[10] However, ripples on the floor of Eagle crater composed of 50-125 μm grains with u_F/u_{*t} only ~0.5 show that the u_F/u_{*t} ratio might characterize particle behavior differently in martian conditions.

Aeolian History of the Site: The abundance of well-sorted basaltic sand grains slightly smaller than the size most easily mobilized implies large transport distances from the basaltic source material, a long, fairly mature attrition history from larger grain sizes and source rocks, or both.

Winds capable of winnowing away finer grains but not coarser clasts can form deflational lags. As the surface concentration of larger, immobile clasts increases, the fraction of wind shear stress available to move loose, finer grains in between is reduced. Deflation seems to have evolved the plains to a uniform threshold shear velocity condition, controlled by spherule fragment armor on the ripples, and whole spherules scattered across the flat areas between. The present day inactivity of the plains provides an upper bound for local wind friction speed u_* associated with current dust storms of ~3-3.5 m/s. (All u_* values herein are calculated from ref[11]).

A fundamental assumption is that the highest energy wind events are the rarest, but can effect the most change. The preserved record is likely to reflect a biased series of progressively stronger and older but more obscure events, with even older or interleaved weaker events being unrepresented even if they were more typical. The most recent events at the landing site involve cycles of bright wind streak erasure and formation caused by winds from 315° or 135° exceeding u_{*t} ~2.0 m/sec (~50 m/s at 1 m) associated with large dust storms. These wind events activate basaltic sand ripples in temporary particle traps like the floor of Eagle crater and, when strong enough, sweep accumulations of trapped material out on to the plains, supplying a very sparse population of mobile sand grains that migrates from one trap to another. Wind-related changes in rover tracks exposed for 200 sols are evidence for these processes.

The more coarsely-surfaced N26E plains ripples have not been active as recently. These ripples formed when one or more strong wind events from around 296° reoriented a pre-existing set of plains bedforms. Winds during this process probably moved the spherule fragments only in creep driven by basaltic sand. (Stronger winds capable of saltating the spherule fragments directly—exceeding u_{*t} ~3.0 m/s, u ~80 m/s at 1 m—probably would not have preserved signs of the pre-existing N4E bedform orientation.) Excellent sorting of the spherule fragment population currently draping plains ripples indicates very strong winds capable of saltating these particles have occurred at the landing site in the past. These winds, with $u_* > 3.0$ m/s ($u > 80$ m/s at 1 m) may have been responsible for fragmenting a source supply of intact spherules through energetic collisions during transport, as well as sorting the fragments. It is unknown how this population became intermingled with the current population of intact spherules that are distributed across the flat areas between plains ripples. We see no evidence yet that sources of the basaltic sand—or the spherule fragments—were local to the site (e.g., weathered from material stratigraphically above current level, since eroded). Such scenarios are possible, but not required. Discovery of a basalt or basalt-enriched rock fragment too large to have been transported far by wind would argue for a local source of this material.

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